Chapter 4

Building Typology Comparison Between Courtyard and Atrium Buildings: A Study of Thermal Comfort and Energy Performance Factors in Different Climate Zones

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Additional information is available at the end of the chapter

http://dx.doi.org/10.5772/66669

Abstract

The aim of the study in this chapter is to investigate performances shown by courtyard buildings, used widely both as microclimate regulators and as city-wide climate stabilizers especially in the hot-dry climate regions. Furthermore, this study examines atrium buildings having an increasing usage rate in recent years and the presence of comfort problems in particular which have not been resolved for different climate regions. Wind velocity measurements are performed in 36 different points determined in X and Y directions and 17 different points in the Z dimension on the outside of the courtyard considered in this study. In addition, both atrium building typology model and courtyard building typology model are obtained by taking the average courtyard dimensions seen in many regions; by covering open space courtyard section of the geometry with a transparent glass, atrium and courtyard typologies can be obtained. Furthermore, thermal comfort states and energy performances of these two different building typologies in interior courtyard and in building internal volumes for hot-dry, hot-humid and cold climate region conditions as well as the effect of solar radiation values exposing the building surfaces and solar movements during the day on the thermal performance on the building are analysed with CFD FloEFD and Star CCM+ software.

Keywords: thermal comfort, building energy performance, courtyard and atrium buildings, air velocity, wind tunnel experimental, numerical analysis, CFD, FloEFD, Star CCM+

1. Introduction

The history of using courtyards could be traced 5000 years back to Egypt. It is one of the architectural elements which are used continuously in different climates and civilisations for thousands of years [1, 2]. The usage of atrium can be traced back to the nineteenth century in

Europe after development of steel and glass technologies. Nowadays, highly glazed atriums are constructed for many different purposes in different climates [3–5]. Contemporary architecture mainly focuses on environmental aspects especially energy conscious forms of buildings. In this regard, recently, certain architectural studies have been conducted to understand the effects of these transitional spaces on buildings' energy consumption [6]. Two main types of transitional spaces, courtyard and atrium, are used widely all over the world.

Architects look for most appropriate design strategies in climatic responsive designs to integrate them with building designs in order to enhance their performance. Using both courtyard and atrium in different climates without considering their performance in different climatic conditions will cause energy-related concerns, which should be eliminated. It is important for designers to understand how different climates affect energy performance of courtyard and atrium buildings and which building type is more energy efficient in different climates.

There are many types of architectural zones which moderates the outdoor and indoor climatic conditions without mechanical control systems. These zones are called transitional spaces. They can be closed, such as atrium, or semi-closed, such as balcony and porch, or open, such as courtyard and patio [7].

1.1. Definition of atrium buildings

Atrium-building typology is defined as building of two or more storeys high open space that is enclosed with a roof and having vertical volumes surrounded with usable areas. Atriums are open public spaces where people engage in activities, e.g. to walk around, meet, talk, wait and rest. When the evaluations are made in terms of the systems used in atriums, it can be seen that there is no common solution agreed upon. Because of their spatial role, atrium-building typologies which form the centre of buildings create a buffer zone between the building and the external environment whilst providing vertical and horizontal circulation between the layers. Atrium-building typologies play an important role for various purposes in multi-storeyed commercial and institutional buildings; for instance serving as foyers, building entrances, exhibition hallways. When they are compared with traditional buildings, atrium-building typologies require excessive energy consumption in terms of heating and cooling as well as ventilation, since they contain more complex air phenomena (such as the greenhouse effect, buffer zone and air layering). In addition, despite this excessive energy consumption, failure to provide user comfort conditions for a long period of time in an atrium typology building is problematic. Meeting the required performance criteria for reducing energy consumption and to provide user comfort in atrium type buildings is possible by careful selection of the glass system which is used particularly in the atrium hall and by designing the building geometry according to climatic conditions.

When atrium-building typologies are compared to classical buildings, due to the fact that they contain complex climate events (sera effect, tampon area, air layering, etc.); they require extreme energy consumption for heating, cooling and for ventilation purposes. In spite of this, extreme energy consumption, the failure to obtain comfort conditions for users in typology building is seen as a significant problem, especially when the correct glass selection in the glass systems used in atrium hole along with the suitable geometry design compatible with

http://dx.doi.org/10.5772/66669

topography and weather conditions could potentially solve the problems for reducing energy consumption and to obtain user comfort in atrium-type buildings.

Atrium-building typology is a plan type used widely in Europe and worldwide, due to a variety of reasons such as the ability to create innovative and prestigious locations, formation of social and comfortable environments along with maximized advantages due to utilization of sunlight for natural lighting and for warmth, as well as the presence of natural ventilation in these buildings [8].

Since these regions are designed for the actions having no continuity, it is thought to be warmer in the summer and colder in the winter compared to the internal environmental conditions. However, this approach has changed over time to longer-term actions e.g. eating, drinking, sitting and these places are conditioned according to these new developed actions. To meet the increasing user demands together with the rich utilization purposes needed, complex conditions, such as heating, cooling, ventilation, air stratification, ensuring indoor air quality, acoustic and environmental system controls, are experimented [9].

The energy used to obtain necessary comfort levels related to actions of atrium-building typology reaches very high levels. In today's conditions, where the effective use of energy is discussed, the inadequacy of comfort conditions even with high-energy consumption and with the extreme energy usage in atrium-type buildings are discussed as a serious problem.

1.2. Definition of courtyard buildings

1.2.1. Courtyard as a climate moderator

When other studies about courtyard buildings are considered, the recent studies frequently focus on investigating thermal performance within the courtyard. These studies can be classified as air movement in the courtyard, courtyard-building-sun-shadow relationship and thermal performances of courtyard buildings in different climate regions. In a study carried out on evaluating the total-energy performance of a courtyard selection, energy performance of a courtyard building with the same geometry and ratio and the centre atrium energy performance is investigated comparatively [10–12]. In another study, where the effect of building form and its type on climatic performance for various climate regions are studied and from this perspective, the evaluation of the courtyard option is conducted in terms of the environment. Ratti et al. performed numerical analysis studies for the conditions described above [13].

When the studies related to buildings with courtyards are examined, the studies which analyse thermal performance in courtyards are seen very frequently [10]. These studies can be classified as air movement inside the courtyards, the relationship between courtyard-building-shading and the thermal performances of courtyard buildings in different climates [8, 14]. In a study which examined the total energy performance of the courtyard, the energy performance of central atrium and the comparisons with a courtyard building having the same geometry and scale have been examined [15, 16]. In the study where the effect of building style and form has on the climactic performance and where the evaluation of the courtyard option is conducted environmentally, Carlo Ratti, Dana Raydan and Koen Steemers have conducted numerical analysis studies [17].

In another study by Mohsen, which investigated the thermal performance of a courtyard building, evaluated the effects of the geometrical and physical parameters of the courtyard on the solar heat radiation exposed on the front side of the courtyard structure [18]. Muhaisen and Gadi performed several studies on courtyard type and courtyard buildings. These studies mainly focused on the effect of the courtyard type and solar radiation gain as well as the sun-shading effect. The objective of these studies conducted in 2006 was to investigate how to provide adequate amount of solar radiation to obtain the necessary heat for the building in the winter and inner courtyard envelope and courtyard type work needed to reduce the energy necessary for the cooling in summer or to provide sufficient shadow region [19].

In another study, the sun-shadow performance of a courtyard was examined and a mathematical model was developed in order to calculate the shaded and sunny areas of the courtyard building which was designed with a circular geometry. This developed model investigates the interaction between the sun and the courtyard buildings in circular geometry having any ratio or dimension. Muhaisen and Gadi examined the shading performance of polygonal (such as pentagonal, hexagonal or octagonal) shape courtyard types in their study investigating the courtyard style and options [19].

Studies related to thermal performance of the courtyard option using CFD are commonly seen in recent literatures. In the study by Rajapaksha, Nagai and Okumiya, they have examined passive cooling potential in single storey courtyard buildings with dense, massive envelope in a warm, humid climate and they have put forward the criteria and suitability of single-storied, large mass courtyard buildings for passive cooling [20]. In a study by Rajapaksha et al., the passive cooling potential of a single-storeyed highly massive building in a warm-humid climate was examined. They tested the presence of the inner yard space to minimize the heating conditions through an increase of natural ventilation and its optimization [20, 21].

1.3. Thermal comfort behaviours of courtyard and atrium buildings

When the past studies about the courtyard typology and atrium-building typology are examined, it is observed that the energy efficiency and how much the typology effects in terms of climatic comfort as well as how they behave, the relationship and the differences among them are seen to be far from having a comprehensive strategy. Therefore, the aim of the study in this chapter is to investigate what is the relationship between the courtyard and atrium typologies with the most commonly used courtyard geometries according to climatic comfort requirements which are needed for different climate regions and also the meteorological differences as well as the type of behaviour they have in terms of energy performances and comfort conditions.

2. Methodology

2.1. CFD-numerical analysis process

In this study, Star CCM+ software is used for CFD (computational fluid dynamics) analysis. For the hardware resource, a supercomputer located in the Energy Systems Laboratory at Texas Engineering Experiment Station has been used for analysis of the total energy performances of both building options in terms of energy gain-loss in the building within the cooling period in summer (July 21) and the cooling period in winter (January 21) for both building typologies and for three different climate regions are evaluated. From the raw data obtained through CFD Star CCM+, total heat transfer amount and solar radiation gain tables of vertical and horizontal surfaces for all the buildings related to the period of 24 hours encompassing January 21 and July 21 are created for all three climate regions. Numerical values obtained from the tables are reported separately according to the total volume of both the total surface area of the building and the total volume of the building. CFD Star CCM+ software used in this study has also considered and calculated the effect of the shadow regions on the courtyard and building surfaces through sundials during the day for the purposes of heating and cooling requirements of the courtyard building.

2.2. Experimental wind tunnel process

Interior courtyard wind velocity measurements performed in the experimental period of this study is conducted in the wind tunnel in Physical Environmental Control located in the Istanbul Technical University- Faculty of Architecture. Interior courtyard wind velocity measurements are performed between courtyard ground point and a height of 2h. Flow speed measurements are performed with computer aid under the guidance of 'Streamline 3.03' software. In order to obtain velocity distribution both with and without a model belonging to the observation room, 'Streamline 3.03' CTA (Constant temperature) hot-wire type anemometer made by DANTEC company has been used.

A part of the statistical analysis and visual expression of the measurements have been accomplished with 'DANTEC's anemometer and a commercial software called 'ACQWIRE' which has been developed for controlling traversing systems. Therefore, in addition to the anemometer, a PC and a printer constitute the main parts of the hardware.

The units used in the setup are composed of 'Traversing system', one 57 B120 motor controller for manual control and 56 G 00 CTA 'interface' computer connector and two arms moving in one dimension carrying measurement terminals (DANTEC), as well as Turkish Q keyboard and Mouse, P11 and P15 type probes. Measurements are made compatible with PC via a software package called 'Streamline 3.03'. 'National Instrument' is developed by 'DANTEC' for hot wire anemometers. With this software; obtaining data, transforming electrical voltage variation obtained from the hot wire probe into velocity, as well as storing the measured data as files, calculating turbulence intensity and average speed data and evaluating them by transforming all of these into the plots are possible.

2.2.1. Properties of the wind tunnel

Physical Environment Control Wind Tunnel of Istanbul Technical University (I.T.U) Department of Architecture is a subsonic, open rotated, closed jet wind tunnel with Eiffel-type absorption. Tunnel entrance starts with 2.50 × 2.50 m × 0.30 m bell mouth. Subsequently, there are two flow formatting sections. For the connection between the flows formatting section to the observation chamber, there is an adapter module passing from 2.00 m × 2.00 m cross-section to the 1.05 m × 1.05 m cross-section. Collector section, where the air absorption takes place, is built by a sheet metal with 4 m^2 of cross-section, 3.40 m height and 2.00 mm of thickness. The air absorbed in this section reaches to the observation room with 1 m^2 cross-section by making the air parallel to the tunnel with the help of the bell mouth collector. In the end of the diffuser, total of 5.96 m long providing circular cross section with a diameter of r = 1.64 m of 1.05 × 1.05 m^2 cross-section is connected to fan pulley with 0.52 m diameter, which is connected to another fan pulley with a 0.52 m diameter. The fan utilized in the tunnel is an axial fan. The power of the motor rotating the fan is 1.5 kW and the rotation speed is 1450 rev/min (**Figure 1**).

Thirty-six different measurement points are determined in X and Y dimensions in the courtyard and measurement profiles with 34 measurement points are identified in the Z dimension.

According to the profile, a total of nine measurement points which are spaced with a distance of 0.5 cm are determined in the interval between 0 and 4 cm. due to the region where the first boxes of 4.00 cm are located. In the next section up to 10.00 cm, six measurement points with 1.00 of separation are identified. A total of 14 measurement points are identified with 0.5 cm separation again for the region between 10.00 and 17.00 cm. Finally, five measurement points between 17.00 and 22.00 cm are identified. Then the probe has been placed in the observation room of the wind tunnel (**Figures 2** and **3**).

Measurement points located parallel to the side face of the observation room of the wind tunnel are the 'A.B.C.D.E.F.' points. These points are also parallel to the wind direction. '1.2.3.4.5.6.' measurement points are the measurement points which are perpendicular to the wind direction (**Figure 3**).

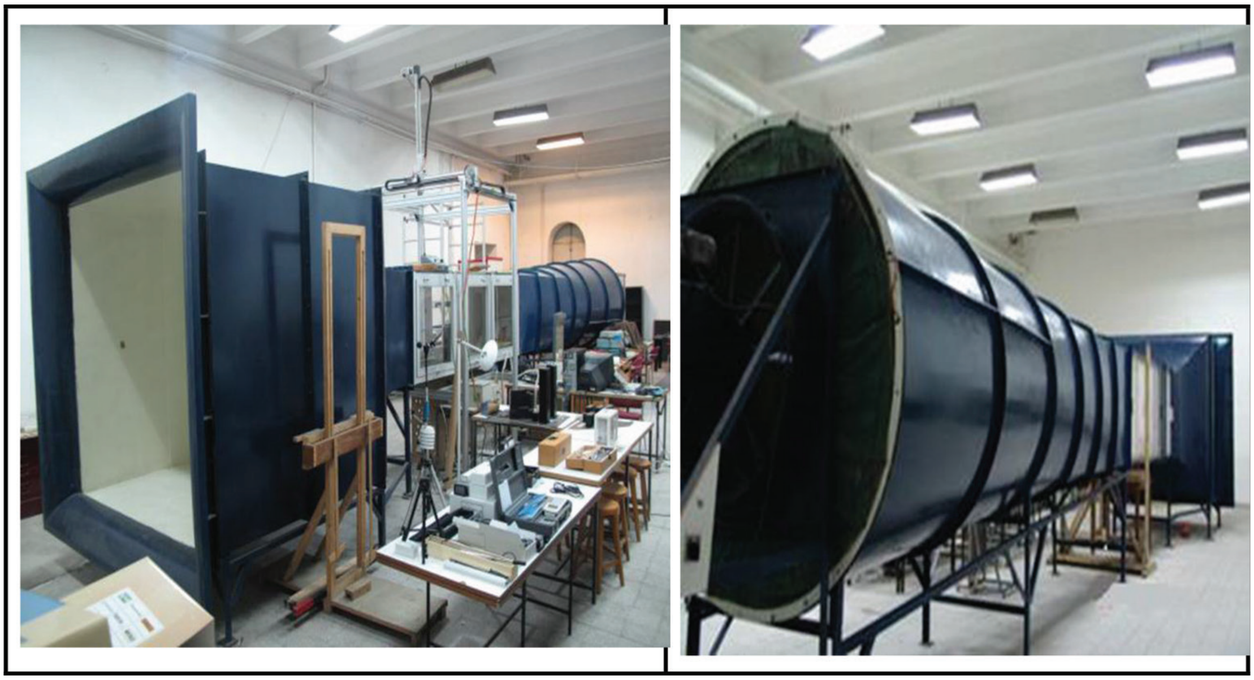

Figure 1. General view of the wind tunnel in Istanbul Technical University-Department of Architecture-Physical Environmental Control Laboratory.

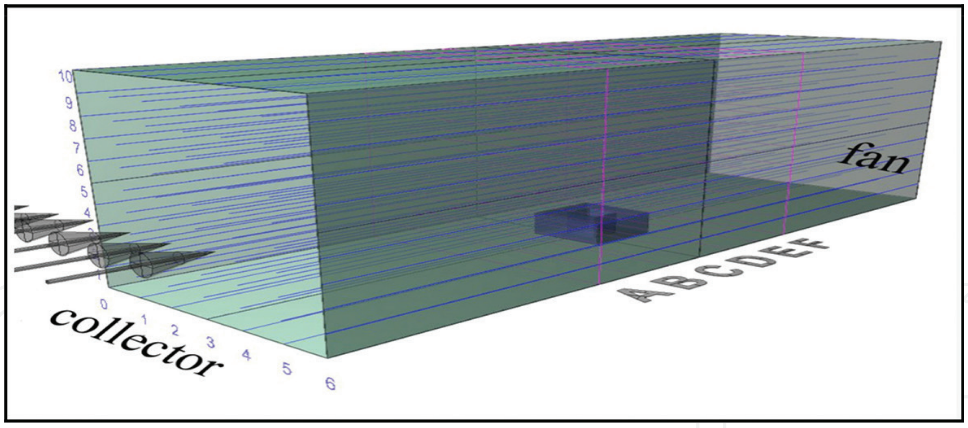

Figure 2. Model and measurement point axis views in the tunnel-positions of measurement axis on the lateral surface of the wind tunnel observation section.

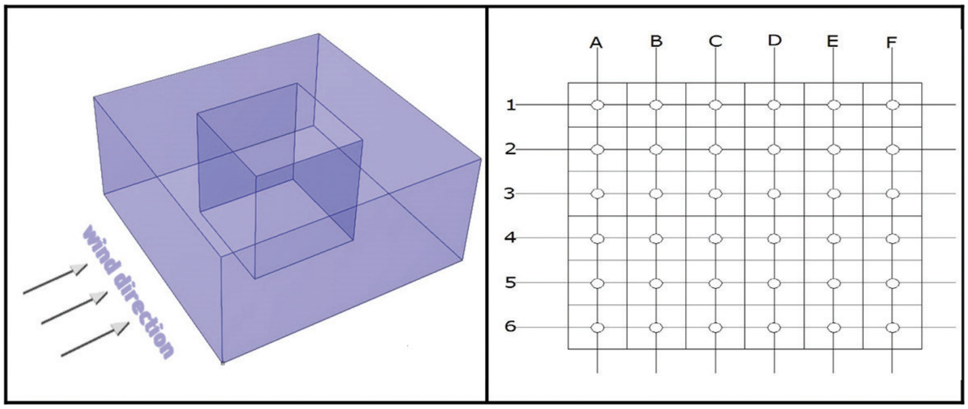

Figure 3. Thirty-six different measurement points for the model courtyard being measured.

Thirty-six different measurement points identified in the courtyard model used in this study are shown in **Figure 3**. There are total of 36 points including six of each in every dimension with 2.00 cm intervals in X and *Y* dimensions within 12.00 × 12.00 × 12.00 cm courtyard. These points are named as 'A1, A2, A3, A4, A5, A6—B1, B2, B3, B4, B5, B6—C1, C2, C3, C4, C5, C6—D1, D2, D3, D4, D5, D6—E1, E2, E3, E4, E5, E6—F1, F2, F3, F4, F5, F6' (**Figure 3**).

Interior courtyard measurement values of the discussed courtyard building typology and the measurement results made in the windward area are explained with table and plots. Then the measurement values in '0.00H–0.25H–0.50H–0.75H–1.00H–1.25H–1.50H–1.75H' levels are evaluated with tables and plots and these values are compared with each other (**Figure 3**).

2.3. Reference building considered for the courtyard and atrium typology

For both the chosen courtyard and atrium-type buildings, the numerical analysis and the courtyard building typology where the interior courtyard wind-velocity measurement are performed in the wind tunnel is designed as two floors, with 3.00 m floor height and with 14.00 × 14.00 × 6.00 m. outside of the building sizes and 6.00 × 6.00 × 6.00 m courtyard dimensions (**Figure 4**). At the same time, all geometrical information and building envelope information related with the courtyard typology is benefitted from the courtyard information considered in E. Yasa, V. Ok. 2014.

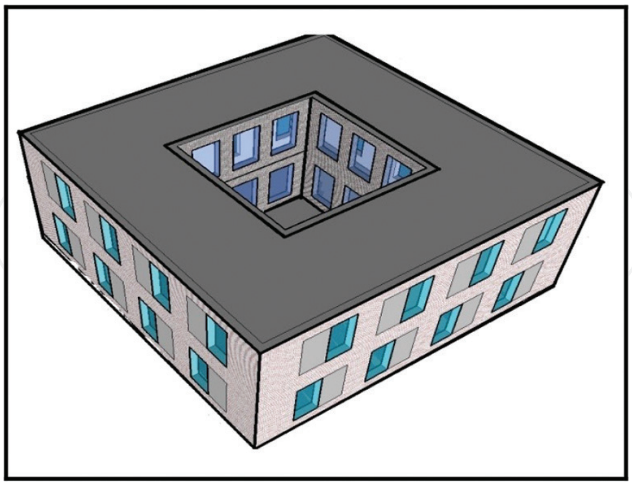

Figure 4. The plan and perspective for the reference courtyard-building (with two storeys, with a floor height of 3.00 m and with external building dimensions of 14.00 × 14.00 × 6.00 m and courtyard dimensions of 6.00 × 6.00 × 6.00 m.

3. Case study methodology and creating a model geometry for CFD

For the opacity and permeability values on the transparent surfaces of the building used for both types of buildings in this study; reflectivity is set at 10%, absorption is set at 26% and the permeability is set at 64%. Thickness, density, specific heat, thermal conductivity coefficient, solar radiation absorption, solar radiation reflectivity, surface roughness, layer number information as well as separate layers as mezzanine, roof tiles sitting on the ground and the layers on the tiling are identified separately (**Table 1**).

Materials	Thickness, dn (m)	Thermal conductivity calculation value, λh W/mk	dn/λn	Ud
Outer plaster	0.030	1.400	0.021	0.378
Rockwool	0.040	0.040	1.000	
Aerated concrete (with mortar proper to TS 4916)	0.200	0.140	1.429	
Inner plaster	0.020	0.870	0.023	
Total		**1/λ**	2.473	

Table 1. Information about the building envelope applied into the whole courtyard and atrium typologies.

These data about the building envelope are also listed in **Table 1**. The data used in the simulation program is completed by entering the values of volume ambient temperature, boundary condition of the surface and heat zones, absorbency of the surfaces, reflectivity, density, specific heat and thermal conductivity (**Table 1**). Data for Antalya which has a hot-humid climate character, Diyarbakır having hot-dry climate character and Erzurum with cold climate character are then entered into the Star CCM+ simulation software. In addition, structure envelope of the building, structure elements and data like reflectance, permeability of the building materials are also inputted. **Figure 5** shows the properties of the examined courtyard and atrium typologies the geometries.

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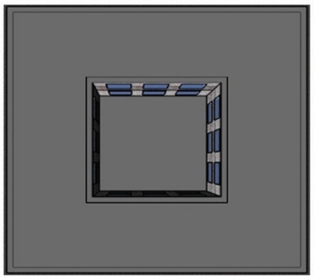
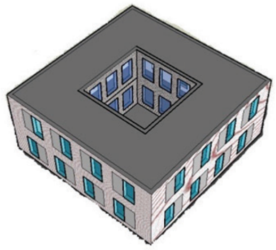
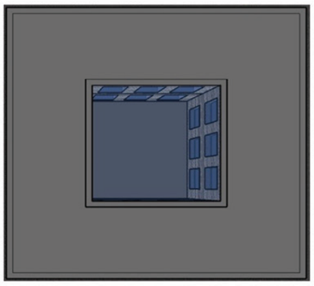
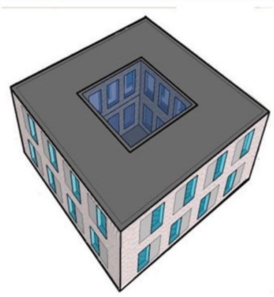
Properties of the Considered Courtyard and Atrium Typologies	
Courtyard Typology	
	
Courtyard Dimensions	6.00m X 6.00m X 6.00m
Building Roof Area	160 m^2
Building Exterior surface area(for Total Heat Transfer)	960 m^2
Building Total Volume	960 m^3
Courtyard Area	36 m^2
Courtyard Volume	216 m^3
Atrium Typology	
	
Atrium Dimensions	6.00 x 9.00 x 6.00
Building Roof Area	184 m^2
Building Exterior surface area(for Total Heat Transfer)	1104 m^2
Building Total Volume	1104 m^3
Courtyard Area	54 m^2
Courtyard Volume	324 m^3

Figure 5. Properties of the considered courtyard and atrium typologies.

4. Limitations and assumptions in the case study

This study is limited to comparative analysis between courtyard and atrium typology options considered for application in plot centres of 'Hot-Dry Climate', 'Hot-Humid Climate' and 'Cold Climate' with different characteristics dominant in Turkey. The courtyard and atrium are of same size and volume. Total of analysis consists 24 hours of analysis for each option has been made separately on hourly basis. For each building typology, 7th month and 21st day, in other words, July 21 constituting the example of the hottest period has been elected as the average of the long-term meteorological data for summer months or cooling period instead of all months and days of a year; and 1st month and 21st day, in other words, January 21, the example of the coldest period, has been elected as the average of the longest period meteorological data average for the winter months or heating period. To represent the three distinct climatic regions examined in the study, 'Diyarbakır-DB' was chosen for the hot-dry climatic region, 'Antalya-ANT' for the hot-humid climatic region and 'Erzurum-ERZ' for cold climatic region and long-term average meteorological climate data pertaining to such provinces were used.

The reason why these days are discussed is that data where average values are frequently encountered have been found out for the heating and cooling periods having examined the long-term meteorological data. The limitation of the courtyard and atrium building transparent surface rates, however, the transparent surface ratio of the courtyard option in non-building facades is 20%, the ratio of opaque surface is 80% and such ratio is 40% for transparent surface ratio and 60% for opaque surface ratio in building courtyard facades. Opaque and transparent surface for atrium building is exactly the opposite to solar heat gain, all thermal factors were kept the same in the research for the purpose of defining the building's energy needs by estimating to what extent solar radiation is affected by various building typologies. Mechanical HVAC was not included among courtyard building options. The only cause of heat gain is expected to be solar heat gain. Every courtyard and atrium building was considered to have an average floor height of 3.00. In both courtyard and atrium building options, the building was considered to have a comfort limit temperature value of 25°C for heating and cooling loads inside. The user entered the meteorological and topographic data for the building's climatic region. The index of wind direction and intensity, outdoor weather temperatures, the region's sky cloudiness and direct and common solar radiation intensity were generated based on the data from Republic of Turkey General Directorate of Meteorology, which constituted the meteorological data entered to the software.

5. Boundary conditions

Naturally ventilated buildings are subjected to external climatic conditions in terms of their architectural design. The interaction between the indoor and outdoor environment results in an internal airflow pattern. The indoor airflow pattern is significantly affected by natural ventilation and outdoor conditions which in turn directs occupants' thermal sensations. The solar radiation within the building produces heat gain which is then thought to cause buoyancy-driven natural ventilation. This natural ventilation is believed to direct the building's natural ventilation.

Defined as the product of the density, thermal conductivity and specific heat capacity, the heat flux coefficient quantifies a material's ability to absorb heat. It was found that the heat flux coefficient reflects the influence on thermal comfort of different surfaces. Therefore it is used as the basic thermo-physical property which defines materials. Various layers of each element of the building (walls, roof, floor) are considered to have heat flux coefficients as design variables. Various layers' thicknesses in each building element are also considered as design variables [23].

Taking into account the courtyard and atrium building, the data is intensity: 2290 kg/m^3, specific heat capacity C_p: 840 J/kg K, thermal conductivity: 0.96 W/m K, thickness: 2.00 cm for transparent surfaces and thickness: 115 cm, intensity: 1590 kg/m^3, specific heat capacity (C_p): 850 J/kg K, thermal conductivity: 0.65 W/m K for opaque surfaces. k-€ (standard model); near wall treatment: standard wall functions were used as turbulence model, while solar calculation was used for insulation calculation.

Courtyard and atrium options can include materials with different material characteristics, such as air as building shell and fluid and as building components, floorings, doors, windows, walls and roofs. Intensity: 1.2256 kg/m^3, specific heat C_p: 1006.43 J/kg K, heat conduction: 0.0242 W/m K and viscosity: 1.7894e-05 kg/m s are respective values accepted for fluid air. Transmission coefficient was also taken into account; 0.3499 W/m K for doors, 1.3944 W/m K for walls, 0.919 W/m K for roofs and 1.05 W/m K for glasses used in windows. Atrium building thermal conductivity was considered 1.05 W/m K, glass thickness 30 mm, reflection 5%, absorption 65% and penetration 27%.

The indoor comfort limit temperature value for the heating and cooling load within the building on January 21 and July 21 has been considered to be 25°C in both atrium and courtyard building options. As to the opacity and penetration values outdoors, configurations were made for the glasses used at windows as reflection 10%, absorption 34% and penetration 56%. As data entry; the time zone of the buildings, latitude, longitude, cloudiness ratio as well as month, date, time, minute were included. Thermal comfort and radiation model module have also been used for comfort calculation. The extent of absorption of light by the weather and the data of radiation of light indoors has been included therein. Since these factors are very close to zero, they were considered at 0.001098 levels.

6. Numerical solution modelling

Computational fluid dynamics (CFD) programs are powerful design tools that can predict detailed flow movement, temperature distribution and solar heat flux. Recently, computational fluid dynamics has been used to predict convective heat transfer at exterior building surfaces [1–19, 24–30].

Details of temperature distribution, airflow patterns and other comfort parameters would provide a better picture of the resultant thermal performance within the atrium in response to the changes of building design variables. CFD's main advantages for this application are:

1. Ability to analyse a specific or complex building or building configuration,
2. Ability to acquire very high spatial resolution data,

3. For atmospheric conditions, high Reynolds number flows can be incorporated and

4. Access to detailed information on the flow field and the thermal field.

In these previous studies, this allowed for a detailed analysis of, the correlation of heat transfer coefficient distribution over building surfaces; the influence of turbulence and wind direction; the correlation with different reference wind speeds; the thermal boundary layer, etc. However, some important limitations of the applied numerical models have to be emphasized. Considering the building shell for evaluation of the thermal comfort and energy performance of the courtyard and atrium buildings also studied in CFD. A number of layers with varying physical properties and thicknesses constitute the wall section. The outside surface is subject to radiation exchange ($q_{r,\,o}$), convection heat transfer ($q_{c,\,o}$) and solar radiation (I_s) from the sky. The combined convection and heat transfer (q_i) within the inside surface directly defines the extent of air conditioning needed to preserve the intended interior temperature ($T_{f,i}$). The assumptions below were employed in the mathematical model:

- No heat generation is observed.
- Interface resistance is negligible due to good layer contact.
- Negligible thermal properties variation.
- Small composite roof thickness relative to other dimensions.

Therefore it is safe to assume a one-dimensional temperature variation.

Based on daily average wind speed and the direction of heat flow, the convection coefficient is constant. The above assumptions, lead us to a conduction equation which uses the composite roof for directing the heat transfer:

$$\frac{\partial^2 T_j}{\partial x^2} = \frac{1}{\alpha_j}\frac{\partial T_j}{\partial t} \tag{1}$$

Here, 'c' is the specific heat, 'ρ' is the density, k is the thermal conductivity, the subscript j refers to the layer, i.e. j = 1, 2,…, N and α is the thermal diffusivity ($k/\rho c$). For the purpose of obtaining temperature variations and heat-transfer rates subject to prescribed initial and boundary conditions, the problem centres around the fundamental solution of Eq. (1), applied to all layers. Initial temperature was accepted as uniform and equal to outside ambient temperature daily mean values; $T_{f,o,}$ mean.

There are many different correlations in the literature to determine the external heat transfer coefficient for the buildings. Palyvos summarized different correlations found in the literature. On the basis of thirty available linear correlations, Palyvos recommended using the following correlation, Eq. (2) to calculate the heat transfer coefficient (h_c) for windward surfaces: [20]

$$h_c = 4\,V_w + 7.4 \tag{2}$$

where V_w is wind velocity. With zero wind velocity, an external heat transfer coefficient value of 7.4 W/m^2-K was used [20].

http://dx.doi.org/10.5772/66669

The optical properties of the glazed facade surface (semi-transparent), i.e. a solar transmittance of 36% and an absorptivity of 17.5%, were the same as those used in previous studies of an existing atrium building at Concordia University. A single glazed wall with a total overall thickness of 24 mm and an effective thermal conductivity of 0.0626 W/m^2-K was used to simplify the modelling of the glazed façade. Also considered were the radiation exchange between the facade and the sky [23].

The correlation was used to calculate the sky temperature [14],

$$T_{\text{sky}} = [\, \varepsilon_{\text{sky}} \, T_{\text{out}^4}]^{1/4} \tag{3}$$

where the emissivity of the sky, ε_{sky}, was calculated using the relation, $\varepsilon_{\text{sky}} = 0.727 + 0.0060\, T_{\text{out}}$ with an ambient temperature of $T_{\text{out},}$ of 25°C. The heat sources were modelled as a no-slip wall boundary (2.00 × 2.00 m) located in the centre of each floor. In all cases the buoyancy flux value, B, was assumed to be 22.63 × 03 m^4 s^3 (a heat source of 823 W was assumed approximately equivalent to four sitting persons with desktop computers) on each room floor and 14.57 × 103 m^{4}s^3 (a heat source of 530 W was assumed approximately equivalent to seven resting persons) on the atrium floor. A constant relative pressure of 0 Pa was used across the room inlets and the atrium outlet [30].

Other value can be used in the model since the steady periodic solution is independent of the initial temperature distribution. The boundary conditions are given as follows:

(i) Boundary conditions at the inside surface (x = 0):

$$-k_1 \frac{\partial T}{\partial x}\bigg|_{x=0} = h_i(T_{f,i} - T_{x=0}) \tag{4}$$

here h_i is the combined heat-transfer coefficient for inside surface; based on ASHRAE handbook of fundamentals [21]: h_i = 9:26, W/m^{2}K for upward direction of heat flow and h_i = 6:13, W/m^{2}K for downward direction of heat flow:

(ii) Boundary conditions at the outside surface (x = L):

$$-k_N \frac{\partial T}{\partial x}\bigg|_{x=L} = h_{c,o}(T_{x=L} - T_{f,o}) - \lambda I_s - q_{r,o} \tag{5}$$

here $h_{c,o}$ is the exterior surface convection coefficient, $T_{f,o}$ is the exterior ambient temperature and I_s the outside surface 's solar absorptivity.

The coefficient ($h_{c,o}$) is a function of wind speed (υ). Empirical values are taken from Ito et al. [22] as

$$h_{c,o} = 18.63\,\mathrm{V}^{0.605}\ \mathrm{in W/m^2\,K} \tag{6}$$

and

$$\nu = \begin{cases} 0.25\upsilon & \text{if } \upsilon > 2\mathrm{m/s} \\ 0.50\upsilon & \text{if } \upsilon < 2\mathrm{m/s} \end{cases} \tag{7}$$

The temperature ($T_{f,o}$) is determined by a sinusoidal function based on a 24-h period. Here t = 0 corresponds to midnight, as

$$T_{f,o} = T_{f,o,\,\text{mean}} + A_o \sin(\omega t - \phi) \tag{8}$$

here A_o being the amplitude, ω is the frequency and is the phase. The solar radiation (Is) is calculated for horizontal roofs in atrium and courtyard buildings in Turkey, employing the ASHRAE clear-sky model [23–31]. The nonlinear radiation exchange ($q_{r,o}$) is provided by [30–34, 35].

The nonlinear radiation exchange ($q_{r,o}$) is given by,

$$q_{r,o} = \varepsilon\sigma(T_{sky}^4 - T_{x=L}^4) \tag{9}$$

here σ is the Stefan–Boltzmann constant, ε is the surface emissivity and T_{sky} is the sky temperature and is considered equal to ($T_{f,o}$-12).

The airflow patterns in atrium and courtyard buildings and temperature distributions in the atrium and courtyard buildings are governed by the conservation laws of mass, momentum and energy. The mathematical model applied includes the numerical techniques to solve the continuity, Navier–Stokes (N-S) and energy equations for incompressible, three-dimensional and turbulent flow. The general form of the momentum, turbulent kinetic energy, turbulent energy dissipation and energy (temperature for constant heat capacity) equations in the steady state form can be expressed in the general form as follows:

$$\frac{\partial(\rho\, u_i\, \phi)}{\partial x_i} = \frac{\partial}{x_i}\left(\Gamma_\phi \frac{\partial\phi}{\partial x_i}\right) + S_\phi \tag{10}$$

where variable (Ø) is Ø) = (u), (v), (w), (k), (ε), (h, T), respectively, ΓØ is the diffusion coefficient of the variable (Ø) and SØ represents the source terms including the pressure terms, thermal source terms, etc., as appropriate for the variable (Ø) being solved.

6.1. Energy modelling for atrium and courtyard buildings

Heat transfer by thermal radiation, conduction and convection is an extremely important consideration in many modelling cases such as the case being investigated here.

The solar radiation was considered to transmit through the glazing facade wall and heat up interior surfaces of the building, as well as partially absorbed at the glazing facade wall.

In order to determine the temperature distribution in atrium buildings and buoyancy item in energy conservation equation should be solved [32].

$$\frac{\partial\rho T}{\partial t} + \frac{\partial\rho\, V_i\, T}{\partial X_j} = \frac{\partial}{\partial X_j}\left[\Gamma_{T,eff}\frac{\partial T}{\partial X_j}\right] + \frac{q}{c_p} \tag{11}$$

where $\Gamma_{T,eff}$ is the temperature effective diffusivity; q the heat source; C_p is the specific heat at constant pressure.

In this research, the equation below is used to estimate the temperature effective diffusivity.

$$\Gamma_{T,\,\text{eff}} = \frac{\mu_{\text{eff}}}{\text{Pr}_{\text{eff}}} \tag{12}$$

where P_{reff} is the general Prandtl number.

Turbulent effects are united to turbulent effective diffusivity, which is the sum of turbulent diffusivity μ and laminar viscosity coefficient.

$$\mu_{eff} = \mu^{1} + \mu \tag{13}$$

In the assumption of Prandtl-Kolmogorov, turbulent diffusivity μ is the result of turbulent fluctuation momentum energy and turbulent fluctuation dimension. l is used to denote turbulent length proportional scale.

$$\mu 1 = C v \rho\, k^{1/2} \tag{14}$$

where $C_v = 0.5478$ is the empirical constant [33].

7. Modelling and simulation

The typology of examined courtyard and atrium models were depicted and digital mesh networks of each defined atrium and courtyard model were drawn, together with thermal regions of each model, model surfaces were generated including restricting conditions. Geographical and climatic data from various climatic regions were then entered into the Star CCM+ simulation program. In addition, data pertaining to constructional materials, constructional components and structure envelope permeability and reflectivity were entered. The thermal regions, building surfaces and elements thereof were determined beforehand. Later, the data for interior thermal gains was entered and analysis was conducted. The criteria included in optimization studies were; 21st day of July for the cooling period in the summer months and 21st day of January for the heating period, hourly, daily, day and night building temperature and average temperature distributions, inter-building total temperature gain and loss values, air direction, air layering, air change ratio for courtyard and atrium buildings' thermal zones, thermal zones among courtyard and atrium buildings, for all building surfaces and roof area; overall and average heat transition amount, surface temperatures, pressures and velocity distributions, inter-building and especially courtyard 1.60, 3.20 and 6.50 m level horizontal-section temperature, pressure and wind speed values were studied and in regard to such values, average temperature and internal temperature distributions, general temperature gain, total temperature loss and gains of sunlight on the surface of the courtyard and atrium building were estimated. In order to provide better cooling and ventilation throughout the cooling season, inter-building temperature gains and losses throughout the heating season were estimated and evaluations were carried out in order to reveal the effects of such results on cooling and ventilation load. All such values were presented in numerical and visual reports and evaluations were conducted and comments were made on internal temperature and average temperature distributions on the courtyard and atrium building surface, overall temperature gain, total temperature loss calculations as well as their effects on cooling and ventilation, based on these values.

In the CFD software Star CCM+ program where the analysis study is performed, information on the building envelope such the thickness, density, specific heat, thermal conductance coefficient, sun-radiation reflectivity, surface roughness, sun radiation absorbency and number of layers are defined whereas layers in the floorings together with (if present) separate stratifications are defined in the mezzanine floor, ground floor and roof slab. The material used in the flooring was examined in terms of its specific heat, density, thickness, surface roughness, sun radiation absorbency, thermal conductance coefficient, sun radiation reflectivity and number of layers. On the other hand, by entering the values of volume ambient temperatures, boundary conditions for surfaces and thermal zones, absorbency of surfaces, density, reflectivity, thermal conductance and specific heat, we were able to acquire the data used in the simulation program.

8. Result and discussion

8.1. Inner courtyard wind tunnel measurements: wind velocity and distribution results

The aim of this section is to determine air movements and the wind velocity that will occur in the courtyard, along with the turbulence values at the predetermined points and then to compare these values with the performed measurements.

First, before moving to the interior courtyard measurements for the courtyard model, velocity profiles are obtained for windward 3–4 axis over the wind and with '0.00 cm–2.00 cm–4.00 cm –6.00 cm' distances from the building on the building surface over the wind region at the building model placed in the observation room of the wind tunnel (**Figure 8**).

According to the velocity profile diagrams obtained as a result of the measurement, wind velocity reaches to 6.00 m/s at H/2 distance away from the building at approximately H/3 height (**Figure 6**).

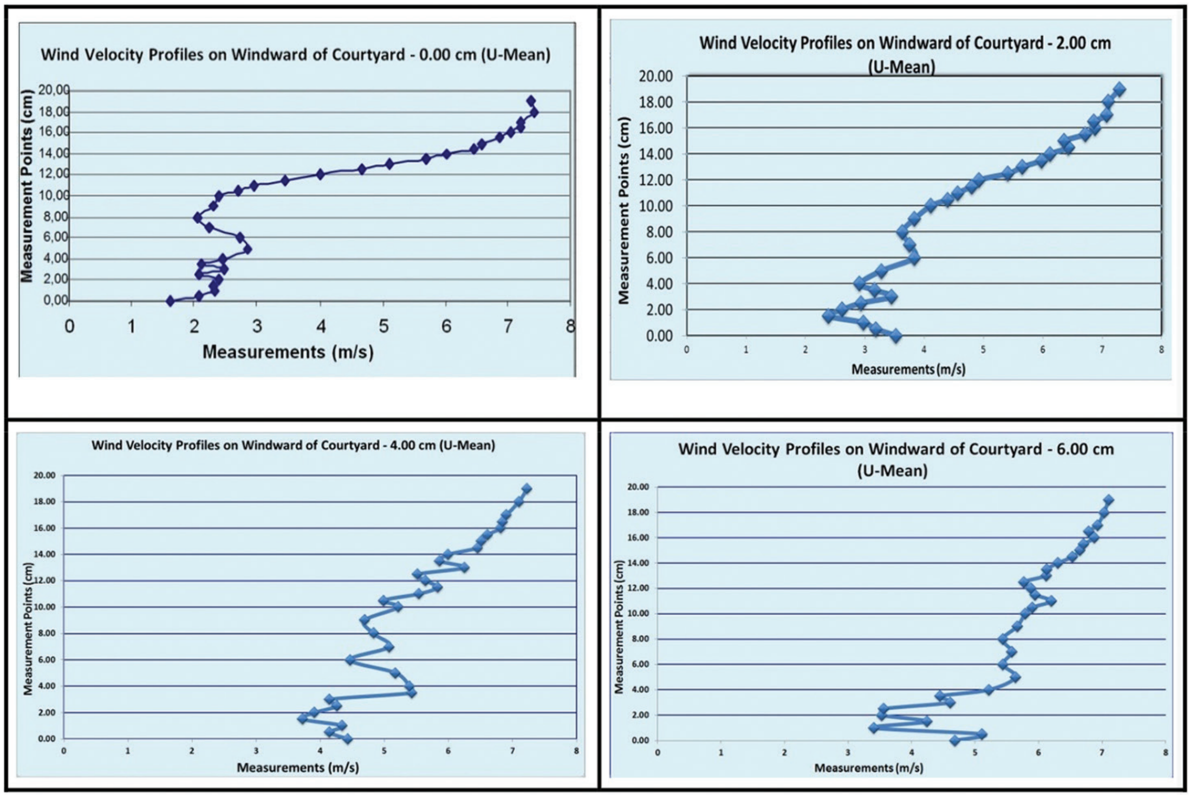


Figure 6. Wind velocity profiles of the windward region of the courtyard typology.

Wind and turbulence values for 0.00 H- Level in courtyard, while wind speed in this level is average of 1.50 m/s in the points B3-B4, maximum velocity for this level in mid points of the courtyard reaches to 2.00–2.50 m/s. Overall average velocity is about 1.00 m/s. The turbulence value at this level is between 40 and 50% compared to the wind speed. As seen in **Figure 9**, as a result of the performed flow monitoring, flow decomposition occurs in the upper limit region, as there is no opening in front of the building (**Figures 7** and **8**).

Wind speed and turbulence values for 0.25H-level in courtyard: wind velocity at this level is between 0.80 and 1.50 m/s. Wind velocity reaches to maximum level at C3 and E2 points. Average wind velocity at this level is about 1.5m/s (**Figure 9**).

Wind speed and turbulence values for 0.50 H-level in courtyard: wind velocity at this level varies showing differences from the other levels in *C*-axis region. Velocity average values are between 0.90 and 1.60 m/s. Wind velocity reaches to the maximum level at the points F3 and F5. The velocity is 1.50 m/s at those points. The average wind velocity at the level is 1.2 m/s (**Figure 10**).

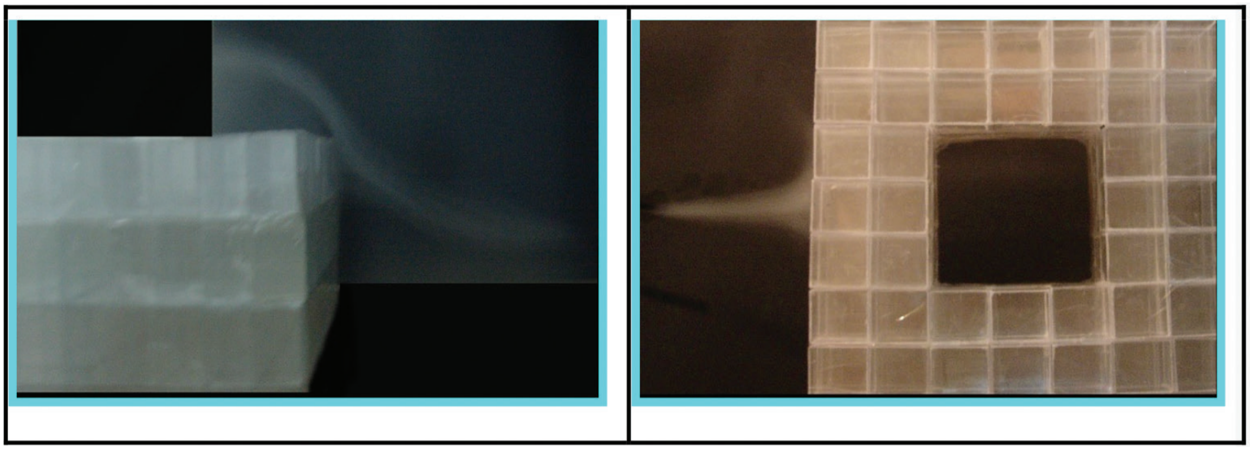


Figure 7. Flow visualization of the courtyard typology model.

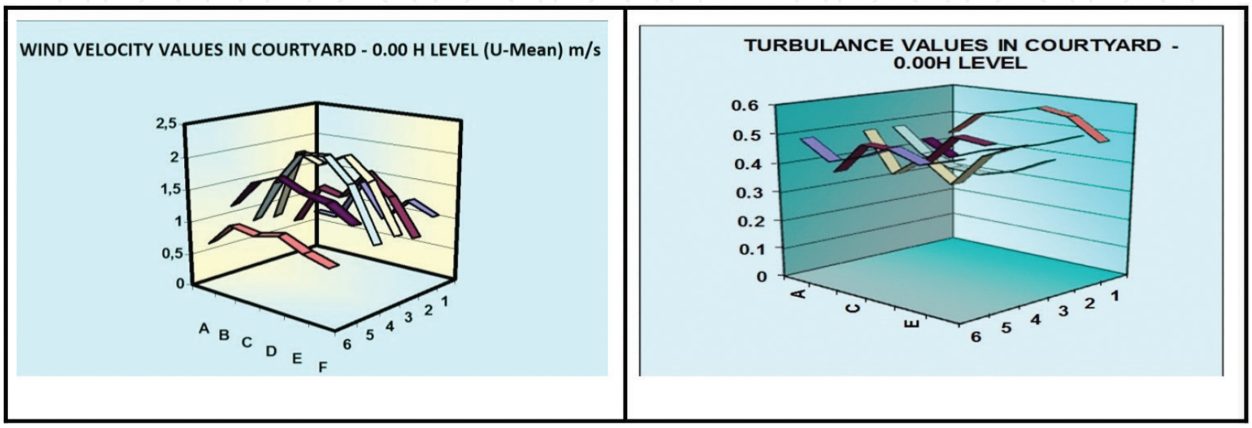


Figure 8. Wind velocity and turbulence values for 0.00 H-level in courtyard.

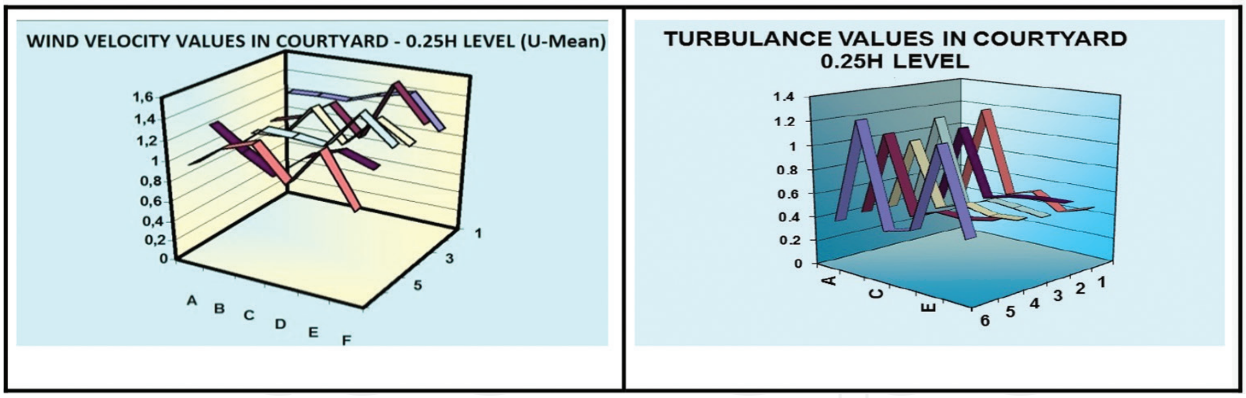


Figure 9. Wind velocity and turbulence values for 0.25 H-level in courtyard.

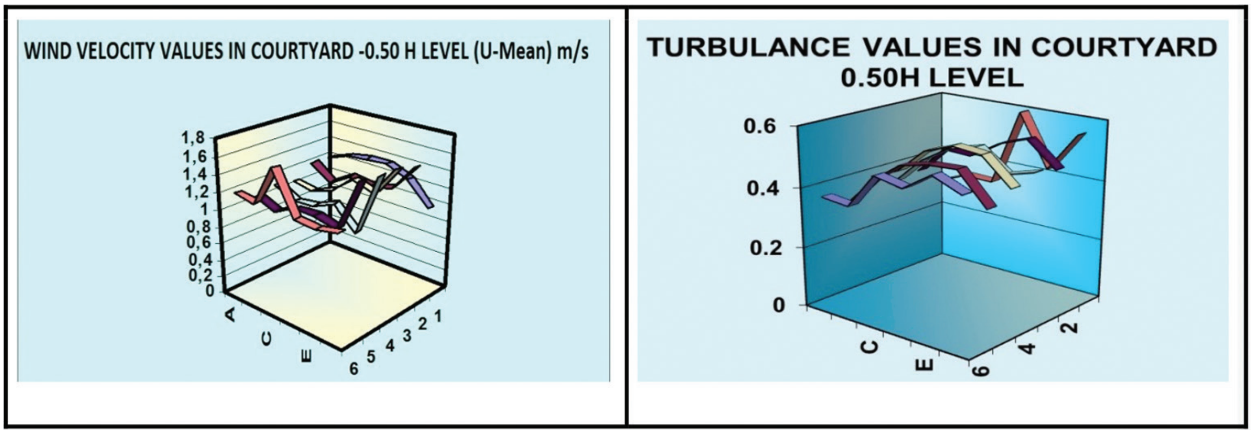


Figure 10. Wind velocity and turbulence values for 0.50 H-level in courtyard.

Wind speed and turbulence values for 0.75H-level in courtyard: wind velocity at this level is between 1.10 and 1.90 m/s. Wind velocity reaches to the maximum level at the points of F3 and F4. Wind velocity at these points is 1.90 m/s. The average wind velocity at this level is about 1.5 m/s (**Figure 11**).

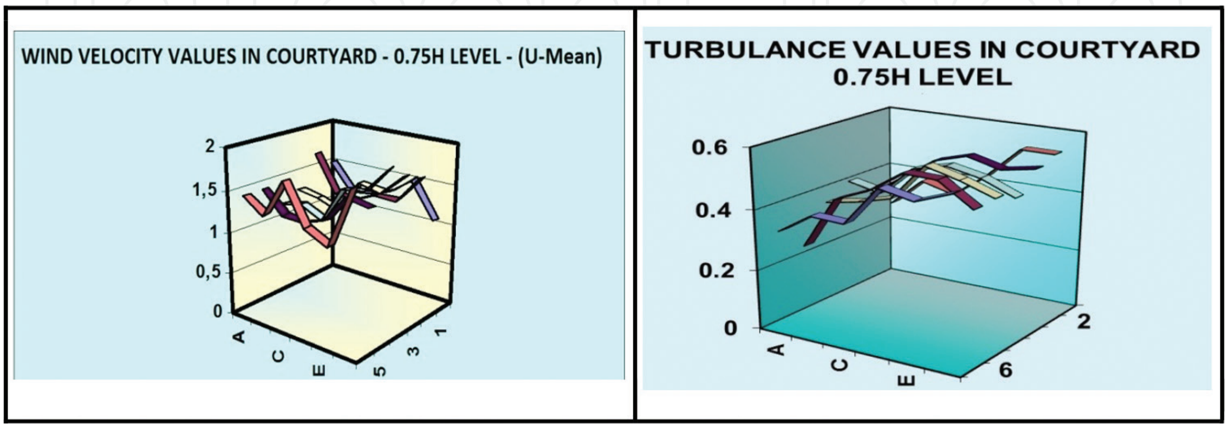


Figure 11. Wind velocity and turbulence values for 0.75 H-level in courtyard.

Wind speed and turbulence values for 1.00 H-level in courtyard: this level is the H level where length, height and width are equal. The wind velocity at this level reaches its maximum at the F4-F5 and F6 points with a value of 2.40–2.50 m/s. Average wind velocity values in the midpoints of the courtyard are about 1.4–1.5 m/s. Overall average is about 1.8 m/s (**Figure 11**). Turbulence value at this level reaches to the lowest 20% level at A1 point and to the highest 50% turbulence level at F1 point. The average turbulence value here is about 40–45% (**Figure 12**).

Wind speed and turbulence values for 1.25 H-level in courtyard: this level is above the H height of the courtyard. Wind velocity at this level is between 1.80 and 3.90 m/s. Wind velocity reaches to its lowest level at C3 with a value of 1.80 m/s and to its maximum level at E6 point. The average wind velocity at this level is 2.50 m/s (**Figure 13**).

8.2. CFD numerical analysis results of the atrium and courtyard configuration

Due to the time and cost issues involved in wind tunnel testing, CFD is now widely employed for the prediction of flow fields. As the range of CFD applications continues to increase, new techniques have been introduced that facilitate its use in both architectural engineering and HVAC (heating ventilating and air conditioning) designs.

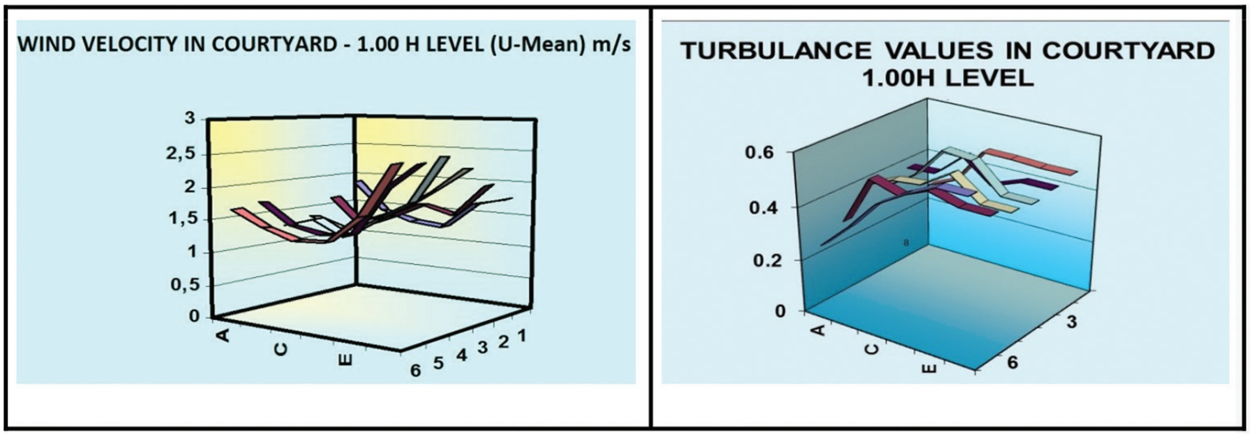


Figure 12. Wind velocity and turbulence values for 1.00 H-level in courtyard.

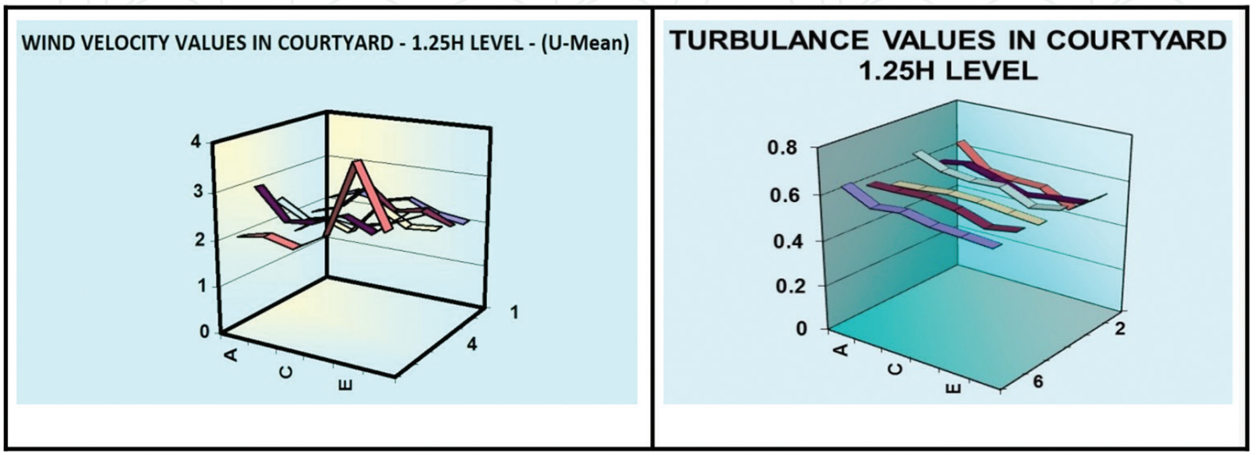


Figure 13. Wind velocity and turbulence values for 1.25 H-level in courtyard.

It is particularly useful for building design and analyses, where it has been applied with considerable success. CFD is used intensively as a tool for evaluating the indoor environment of a building and its interaction with the building envelope, as well as for analysing the outdoor environment surrounding the building.

CFD offers some specific advantages compared to wind tunnel testing. It does not suffer from scaling problems and similarity constraints, because simulations can be performed on full scale. CFD also provides whole-flow field data, i.e. information on the relevant parameters at every position in the model, while wind-tunnel measurements are generally only performed at a limited number of selected positions. However, the reliability and accuracy of CFD are important concerns and solution verification and validation studies are imperative.

For all the three climate regions during the night hours through the least warm period of January 21; the total heat loss of the buildings of the atrium type is greater than the courtyard-type buildings. Minimum heat loss is desired at the whole building during this period. Average heat loss is between (-100) and (-400) W/m^2. The highest heat loss is observed during the night hours.

The maximum heat loss is about (-290) W/m^2 in Antalya, (-300) W/m^2 in Diyarbakır, (–400) W/m^2 in Erzurum for the atrium option. However, heat gain at the whole building for atrium option in Antalya and Diyarbakır regions is higher than the option of a building with an open top particularly from noon hours through the daylight.

According to this table, when the heat gain or the losses at the whole building for the energy performances through the January 21 heating period are evaluated, it is observed that in the case when courtyard or atrium is preferred in the hot-dry climate region (DB) for the both building options, atrium option is more suitable through the January 21 heating period in terms of both night and daylight performances (**Figure 15**). When we look at the 24 hours total gain for the cold climate regions, atrium option seems to provide more gain. In this case, in terms of energy performance between the courtyard and atrium options during January 21 periods for Erzurum, it can be concluded that the atrium is more suitable (**Figure 14**).

In the courtyard option through the night hours during the hottest July 21 period; whole building surface area heat gain amount for all the climate regions is less than the atrium option. During this period, the least heat gain is required. However, especially when we observe the heat gain during the morning to noon hours through the hottest July 21 cooling period, it is seen that the whole building heat gain for the courtyard typology for Antalya's hot-humid climate region is quite high compared to the atrium typology. During this time-period heat gains are about 2500–2700 W/m^2 in Antalya, 3600 W/m^2 in Diyarbakır and 2200 W/m^2 in Erzurum. The heat gain ratio of the courtyard option during the noon hours of 12.00–13.00 reaches to the twice the value of the atrium option. When the plot values for Diyarbakır, hot-dry climate region are examined, whole building heat gain, similar to the gain of the glass courtyard option in Antalya is seen to be greater than the atrium option.

http://dx.doi.org/10.5772/66669

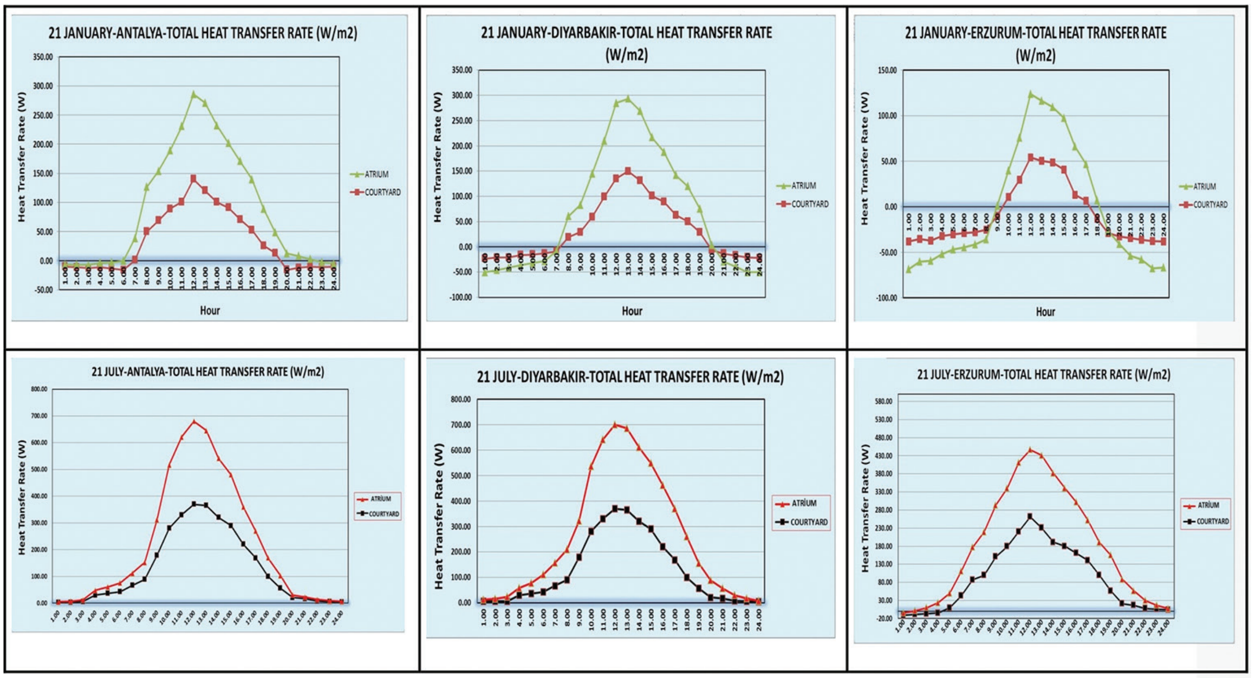


Figure 14. 21 January–21 July total heat transfer rate for each total whole building surface area to atrium and courtyard configuration.

8.3. Temperature values on the front surfaces looking at the courtyard and atrium part and thermal comfort in atrium and courtyard typologies

Outside temperature is a climate element varying periodically depending on the rising angle of the sun. It varies depending on the heat, the current latitude, season, time of the day, topographic structure (slope) and the height. The heat increases during the summer months and when the location gets closer to the equator.

Wind and humid elements are also effective on the heat. South-directional winds increase the heat, but north-directional winds decrease the heat. On the other hand, the humidity-temperature difference for both daily and annual periods are decreased and affect the perceived temperature value by preventing overheating or cooling of a region.

Wind flow conditions and wind velocities around and outside of the building and the temperature of the front side which is looking at the outside of the building and the surface temperature values at the front sides looking at the courtyard in courtyard typology vary quite a lot comparing to the atrium typology, since the velocities and directions of the winds in the courtyard are different. Therefore, in almost all of the day hours, both the wind speeds in the courtyard and the surface temperatures at the surfaces of the building facing the courtyard are lower, as compared to the surfaces looking toward the exterior of the building and as compared to the atrium typology.

If we look at the building surface temperature values, for example, in the courtyard typology option analysed for Antalya which has a hot-humid climate; the faces looking at the courtyard are seen to be at lower levels compared to the first floor in the ground level in the surface facade from the north side facade analysis. In addition, according to the courtyard building typology geometry, because of the shadow effects on the building surfaces, surface heat values where no shadow falls are seen to be at higher levels as compared to the shaded areas (**Figure 15**). Since no wind enters into the courtyard since the courtyard is closed in atrium option, surface temperatures on all facades looking at the courtyard are seen to be at the highest level compared to the courtyard option.

When the surface heat values in Antalya north side on January 21 is examined, while the average temperature for courtyard face at 07.00 is 10°C, the surface temperature value for the atrium face at the same hour is observed to be about 19°C. In courtyard typology option at 14:00 on January 21, surface heat average value is seen to be about 21°C and for the atrium option 35-40°C. On January 21 at 21.00, the heat is seen to go to the heat value at 07.00 which is 10°C (**Figure 15**).

When the surface heat values in the north side of Antalya on July 21 are examined, courtyard surface heat values in the courtyard typology option for 07.00 is about 33°C and the average of the surface heat values is seen to be 38°C for the atrium facade. Since a shade area formed on the façade surfaces looking at the courtyard because of the courtyard geometry at 14.00 on July 21, the average of the shaded area of the façade is about 34°C and the surface average of the un-shaded region is seen to be about 40°C. The average of the surface heat value in the courtyard typology is about 21°C and it is observed to be 40–45°C in the atrium option. The average surface heat values in the courtyard typology option at 21.00 on July 21 are seen to be 21°C and it is 25°C for the atrium option (**Figure 15**).

8.4. The effect of daily solar movement on inner courtyard thermal performance and the courtyard shadowing due to courtyard typology

The exposure of courtyards and atrium building surfaces to the sun or their exposure to a partial shadow is dependent on the position of the sun in the sky as well as on the courtyard geometry. The position of the sun is defined by the solar azimuth angle of the sun and by the elevation angle. These two angles are a function of time and latitude throughout the year. These can be predicted by sun tables prepared for different latitudes or by using possible mathematical equations for numerical computation. The form of the building and its geometry has a large effect on the shadow region produced by the inner surfaces and as a result, it effects the sun radiation received as well as the thermal performance of the building.

The effect of the daily sun activity is dependent on different factors such as the latitude of that region, the year and day of the sun. The movement of the sun is usually symmetric throughout the year for day or night at that particular region. The solar orbit and the movement of the sun during the summer season are higher as compared to the winter season. This daily movement is an important parameter for the formation of the courtyard shape as well as for the formation of the envelope of the courtyard building. The change in the sun's orbital position can be observed very clearly in the winter. The general trend in the winter has shown that the percentage of the sunny area on the shadowed region continues to increase as time passes and gets closer to 12:00 at noon.

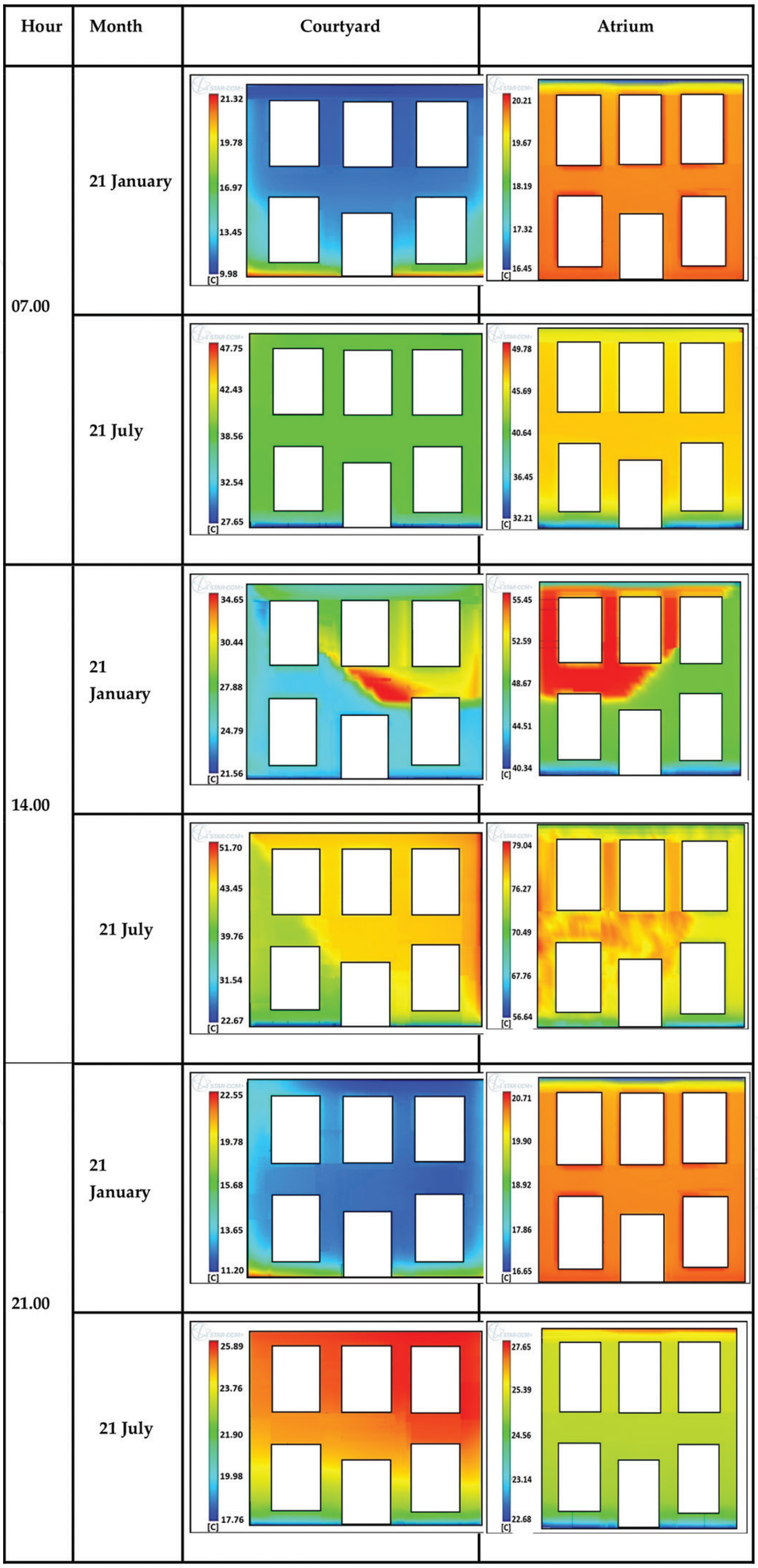


Figure 15. North side temperature values for the faces looking at the courtyard in Antalya, hot-humid climate region.

As the time passes, the percentage of the sunny area slowly increases. During the noon hours, the maximum area exposed to the sun has been observed as 45, 2617 and 4.5%. These results have been mentioned in the sun-shadow analysis section in the study of Ph.D. thesis “A method developed in the optimization of courtyard building shape according climatic performance in different climate regions” by E.Yasa [36]. It has clearly shown that in the winter, with the increase in the latitude the surface area exposed to the sun would decrease throughout the day at any time. In Antalya, on January 21at no time during the day, the sunlight comes to the courtyard and as a result the ground of the courtyard remains in shadow at all hours of the day. In retrospect, wind flow enters the courtyard at every hour of the day. At July 21, during the time of 10:00-12.00-14.00, the courtyard ground receives sunlight and during other hours, for every courtyard option, the courtyard completely remains in the shadow.

8.5. The effect of courtyard and atrium building typology on courtyard wind conditions and natural ventilation for thermal comfort

The conditions which are suitable for human comfort can change according to the environmental conditions at inside and outside of the building and it can also depend on the user's age, sex, metabolism level and the clothing used. The human body can create heat through its metabolism and as the result of the action, it consumes the heat that it produces. In the architectural design, the purpose should be to create suitable environment for every kind of seasonal comfort conditions.

For both typologies, when the inner building conditions as well as the comfort conditions around the building are studied, it is observed that in courtyard typology, the wind flow and velocity on the exterior as well as around the surroundings of the building are very different as compared to the atrium typology.

When the turbulence and wind flow values for inside the courtyard as well as the exterior of a building with a courtyard are studied; it is observed that for the hot-dry climate region and for the hot-humid region, it is seen that 2.00 m/s of wind values are seen on the average outside of the courtyard. However, on the inside of the courtyard, a very refreshing and comfortable, mild wind values are obtained for the hot-dry and the hot-humid climate environment. (**Figure 16**)

The leading wind vectors for the studied period of 07:00-14:00-21:00 in the numerical analysis is given in **Table 2**.

When the inner courtyard wind tunnel velocity measurement experiments are compared, it is observed that there are formations of turbulence and vortex at different points of the courtyard. (**Figure 16**). But vortex inside the courtyard is not affected. Moreover, it is observed in **Figure 16** that the air speed and turbulence values inside and outside the courtyard is quite different between the different levels all sides of the courtyard. Inside the courtyard, the wind cycle and wind velocity, along with more cycles and turbulence magnitude values are seen during the different times of the day.

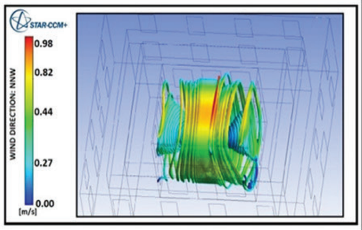
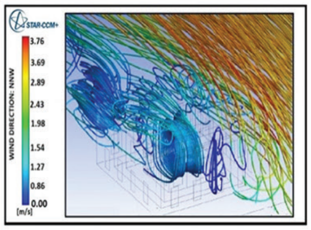
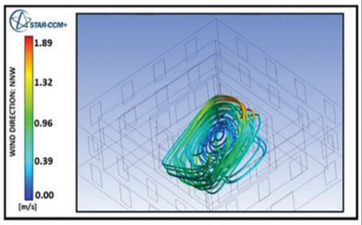
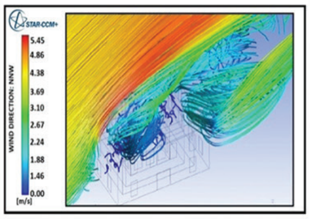
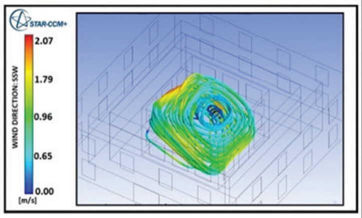
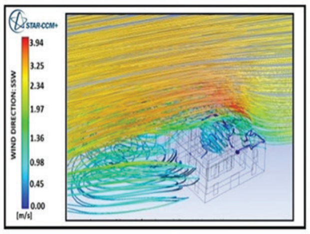
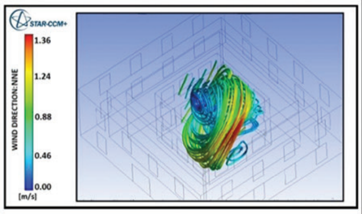
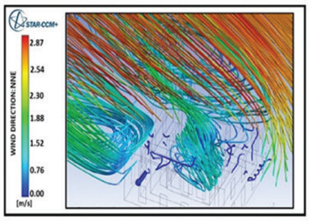
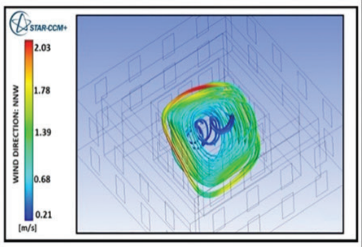
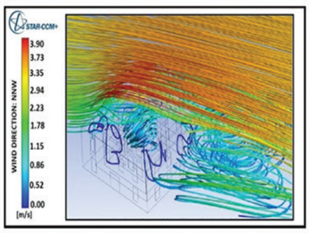
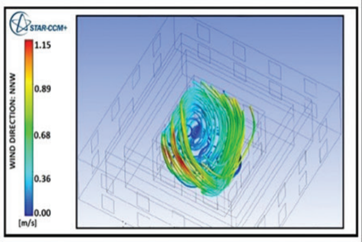
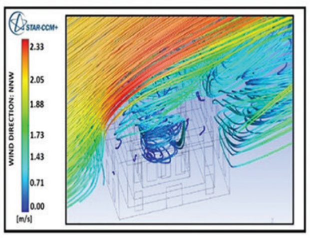
Hour	Month	Inner Courtyard	Around Courtyard Building
07.00	21 January Antalya		
	21 July Antalya		
14.00	21 January Antalya		
	21 July Antalya		
21.00	21 January Antalya		
	21 July Antalya		

Figure 16. The wind flow and turbulence streamline values for inner courtyard and exterior of courtyard in Antalya for the hot-humid climate region.

City	Antalya (ANT)		Diyarbakir (DB)		Erzurum (ERZ)	
Month	**January**	**July**	**January**	**July**	**January**	**July**
07:00	NNW	NNW	WNW	WNW	WSW	ENE
14:00	SSW	NNE	NNW	ENE	W	ENE
21:00	NNW	NNW	WNW	NNW	SSE	ENE

Table 2. The leading wind vectors for the studied period of 07:00-14:00-21:00 for long-term meteorological mean values for three different climate regions for the courtyard typology.

8.6. The evaluation of inner courtyard thermal comfort as per wind tunnel experiments and CFD numerical analysis

The primary thermal performance of the courtyard depends primarily on the shape feature of the courtyard structure and dependent on the envelope of the structure's envelope; it can show changes related to amount of solar radiation which permeates inside from the opaque surfaces and as per the position of the sun. In order to obtain suitable comfort conditions, different strategies are utilized for different climate regions. However, all of them would create an advantage only when there is comfort required inside and when the solar radiation causes comfort or discomfort. Shading would allow for escape from heat retention in the summer, while avoiding shading in winter in order to retain the heat would be the primary rule.

The geometry of the courtyard form would strongly affect the shaded area ratio created by inner surfaces and as a result, it affects the solar radiation which is received as well as the thermal performance of the building. It is generally seen that deep courtyard forms are recommended in order to gain the maximum interior shaded area in the summer. However, in the winter using the shallow form for obtaining sunny areas would be a better solution. The courtyard ground would have a small effect in the winter on the heat production and heat transfer due to solar radiation; but in the winter this effect is less noticeable.

The study by Taleghani et al. on the effect of different building styles on building comfort and energy performance as well as the study by Yasa et al., on different courtyard types on energy and comfort as depending on the climate zone are the studies which mainly discuss the issue at large [22, 25, 34, 35].

Taleghani et al. made a comparison between different building forms regarding the effect of different building typologies on indoor energy and comfort. They showed, all else being equal, that the larger surface to volume ratio of a courtyard building (and its envelopes), the higher heat loss and consequently energy demand for heating compared to a building with no open space. The current research added a linear building type to these comparisons, using 1-, 2- and 3- storey models [25, 34, 35].

Although it is found that the courtyard dwelling performing with less energy efficiency compared to a building with a square floor plan of the same size, the present study showed that the courtyard dwelling was more energy-efficient. This discrepancy can be understood with reference to the surface to volume ratio of the dwellings with a square floor plan.

From the energy point of view, the energy consumption for heating and lighting of the single and linear shape models increases when the number of floors in the models increases. This amount is slightly decreased for the courtyard shape. This observation also applies to the 2- and 3-storey models (average of all floors). In this case, by increasing the number of floors, it is observed that the average of the number of comfort hours in the single-zone building decreases.

Conversely, the average of the number of comfort hours in the linear and the courtyard shape model increases by increasing the number of levels from one to three.

It is observed that the comfort situation on January 21 for the places which are oriented towards the atrium is at higher values for the surface temperature values as compared to a courtyard dwelling. Hence, in the January 21 heating periods, the atrium typology may be preferred from energy performance point of view. The reason for the optimization for different climates for inner courtyard comfort would be to obtain sufficient sun radiation (heat convection) and to either reduce the need for cooling or to get rid of it completely by creating sufficient shading in the summer. The sunrays (radiation) received by the courtyard is seen as the primary factor which affects the thermal performance of the building. The irradiation ratio usually depends on the location of the building, the climate conditions of the location, the time of the year and the configuration of the courtyard. The solar radiation which is absorbed has the function of increasing the surface temperatures and as a result it will increase the temperature of the nearby air layers. This has an important effect on the thermal conditions of the courtyard empty area. As a result, it is required to allow for maximum amount of solar irradiation to enter the courtyard, so that the thermal performance can be achieved both in summer as well as in the winter. In order to achieve this it is evident that proper configuration and proportioning needs to be done in the inner region of the envelope of the courtyard building.

It is observed by calculating between the sunny areas and the shadowed areas that the self-shading generation of the courtyard building on the building surfaces which are oriented towards the courtyard decreases the sunny area by 4%. However in the winter, this self-shading has an effect of increasing the heating load by 12%. Especially in the cold region Erzurum, it is seen that gaining sun radiation in the winter is more important than avoiding it in the summer.

Building surfaces absorb the sun light as long as they are exposed to it. For many opaque surfaces, the area of surface which absorbs the sunlight depends on the absorbance of the surface. On the surfaces which are exposed to the sun, an agreeable strategy would be to restrict the sunrays before they hit the surface. In the hot summer and in relatively colder climates as well as in very cold and in moderate climates, this concept and the effect of the principles show differences. In the above-mentioned environmental conditions, if special design criteria are applied during the design stage of the building, then it can be an effective environmental regulator.

9. Conclusion

According to the CFD numerical analysis, in hot-dry and hot-humid climate, during the heating season, the differences are clearly visible. The average winter monthly heating demand of building courtyard; it is more than of atrium model (excluding summer month 21 July in which the heating demand is zero). The average winter heating season of the year difference for atrium-building typology is higher than courtyard typology. This situation shows that in hot-dry and hot-humid climate covering the transitional space, thereby creating more transparent surface, this could potentially reduce the heating demand for atrium building. Conversely, overheating risk should be checked for atrium typology, which typically increases the number of summer discomfort hours as shown in **Figure 12**. Atrium typology decreases its annual energy use, but increases the number of discomfort hours in the summer. Contrary, courtyard-building typology increases its annual energy use, but decreases discomfort hours in summer.

The courtyard models have a lower number of discomfort hours and higher heating energy demand in comparison with their atrium models. Therefore, for an atrium typology should be used for heating season (limiting heat losses) of the year, whereas the advantages of the courtyard should be used for summer (reducing overheating). When we look at the simulation results, we can see that it would be efficient if we use courtyard option for 21 July cooling season of the year. Comparing buildings with different climatic regions and seasons of the year, the courtyard typology has the smallest number of summer discomfort hours. This is because of the shading effect of the courtyard and wind effect in courtyard for the surrounding building.

Dealing with solar absorption and ventilation in a courtyard is problematic. The dimensions of a courtyard can influence the quantity of sun and wind allowed or blocked. In summer, when we compare the building typology or form; with regard to comfort and energy consumption; less absorption and more ventilation is favourable. Conversely, more sun and less wind are preferable in winter. In summer, the sun angle is high and a compact form provides more shading while a less compact form allows more sun to penetrate in winter. Likewise, a compact form breaks cold winds in winter but is less ventilated in summer. This result can conclude from E. Yasa's Ph.D. thesis and paper [36]. An efficient design strategy could be based on the weight of the heating or cooling energy consumption. Hence, this shows that the design of a courtyard depends on the policies of energy consumption on a national or regional level.

If we compare the orientation effect on building comfort, we can conclude that the North-South orientation provides the coolest microclimate within a courtyard block for a pedestrian. This orientation keeps a courtyard shaded from the early morning till 2 hours before noon and again 2 hours after noon till sunset. Likewise, the indoor environment of the building absorbs the sun while it has provided shading for the courtyard. This makes the North-South orientation the least comfortable model and East-West the most comfortable model in summer from the perspective of the indoor environment. A square plan (like the 6.00 m × 6.00 m × 6.00 m courtyard) could be a balance that satisfies both a person within the courtyard and a dweller inside the building.

In the warm-dry and in the warm-humid climate regions, it has been observed that due to the wind flow entering the courtyard and due to the shading created from the geometry of the building typology; the formation of comfortable areas takes place, especially during the cooling period. It is observed that in the hot and humid regions, the thermal conditions in the summer nights can reach warm temperature values similar to day values, even though the temperature may be a few degrees lower at night (3 °C to 5°C).

http://dx.doi.org/10.5772/66669

As a result, due to the facts that they contain more complex air patterns and that in order to create the fundamental comfort conditions they have a greater energy consumption and thus the few studies which have been conducted on courtyard- and atrium-type buildings currently are not sufficient to allow generalization of the topic. Hence, the subject matter needs to be investigated further with one on one measurement as well as with the use of both experimental and numerical studies.

Acknowledgments

In this study, numerical simulation section with Star CCM+ was analysed by super computer in Texas A&M University Department of High Performance Super Computing Division.

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References

[1] Defraeye T., Blocken B., Carmeliet J. 2010. CFD analysis of convective heat transfer at the surfaces of a cube immersed in a turbulent boundary layer. International Journal of Heat and Mass Transfer, 53 (1–3), 297–308.

[2] Bagneid A. 2006. The creation of a courtyard microclimate thermal model for the analysis of Courtyard Houses [online] PhD dissertation. Texas A&M University, Texas, USA.

[3] Medi H. 2010. Field study on passive performance of atrium offices [online]. 1st International Graduate Research Symposium on the Built Environment. held 15–16 October 2010 at Middle East Technical University (METU), Turkey.

[4] Hung WY. 2003. Architectural aspects of atrium. International Journal on Engineering Performance-Based Fire Codes, 5 (4), 131–137.

[5] Goulding JR., Lewis O. and Steemers TC. (eds.) 1993. Energy in Architecture: The European Passive Solar Handbook. London: B.T. Batsford Limited.

[6] Samant S. 2011. A parametric investigation of the influence of atrium facades on the daylight performance of atrium buildings [online]. PhD Thesis.

[7] Taleghani M., Tenpierik M. and Dobbelsteen A. 2012. Environmental impact of courtyards: a review and comparison of residential courtyard buildings in different climates. Journal of Green Building, 7 (2), 113–136.

[8] Saxon R. 1986. Atrium Buildings Development and Design, The Architectural Press, 2nd edition, London.

[9] Mills FA. 1994. Energy efficient commercial atrium buildings. ASHRAE Transactions, 100 (1), 665–675.

[10] Chun et al. 2004. Thermal comfort in transitional spaces- basic concepts: literature review and trial measurement. Building and Environment, 39 (2004), 1187–1192.

[11] Safarzadeh H., Bahadori MN. 2005. Airflow in Buildings with Courtyards. School of Mechanical Engineering, Sharif University of Technology, Tehran, I. R. of Iran. 2005.

[12] Aldawoud, A., 2008. "Thermal Performance Of Courtyard Buildings", Energy and Buildings 40 (2008) 906–910.

[13] Meir I. A., 2000. "Courtyard Microclimate: A hot arid region case study" in Steemers K. & S. Yannas (eds.) (2000) Architecture-City-Environment.Proc. 17th PLEA Int. Conf. Cambridge, UK July 2nd-5th - refereed papers, pp. 218–222.

[14] Dunham DD. 1990. The courtyard house as temperature regulator. New Scientist, 8, 663–666.

[15] Mabb J. 2008. Modification of Atrium Design to Improve Performance: Atrium Building Physics, Berlin: Verlag Dr. Muller.

[16] Aldawoud A., Clark, R. 2007. Comparative analysis of energy performance between courtyard and atrium in buildings. Energy and Building, 40 (3), 209–214.

[17] Ratti C., Raydan D., Steemers K. 2003. Building form and environmental performance: archetypes, analysis and an arid climate. Energy and Buildings, 35, 49–59.

[18] Mohsen MA. 1979. Solar radiation and courtyard house forms II: Application of the model. Building and Environment, 14, 185–201.

[19] Muhaisen, AS., Gadi MB. 2006. Shading performance of polygonal courtyard forms. Building and Environment, 41, 1050–1059.

[20] Rajapaksha I. 2004. "Passive Cooling in the Tropics: A Design proposition for Natural Ventilation", Built environments and environmental buildings: Proceedings of the 21st International conference Passive and Low Energy Architecture, Vol.1, M.H. de Wit (ed), PLEA. 2004, Eindhoven, The Netherlands, September 19- 21, pp. 531–536.

[21] Rajapaksha, I., Nagai H., Okumiya M. 2003. A ventilated courtyard as a passive cooling strategy in the warm humid tropics. Renewable Energy, 28(11), 1755–1778.

[22] Yasa, E., Ok, V. 2014. Evaluation of the effects of courtyard building shapes on solar heat gains and energy efficiency according to different climatic regions. Energy and Buildings, 73, 192–199.

[23] Lomas K.J. 1992. Thermal modelling of building envelopes: the state of the art, in: Proceedings of the Symposium on Energy Efficient Buildings, Kowloon, Hong Kong.

[24] Hussain S., Oosthuizen Patrick H. 2013. Numerical study of buoyancy-driven natural ventilation in a simple three-storey atrium building. International Journal of Sustainable Built Environment, 1, 141–157.

[25] Emmel MG., Abadie MO., Mendes N. 2007. New external convective heat transfer coefficient correlations for isolated low-rise buildings. Energy and Buildings, 39(3), 335–342.

[26] Blocken B., Defraeye T., Derome D., Carmeliet J. 2009. High-resolution CFD simulations for forced convective heat transfer coefficients at the facade of a low-rise building. Building and Environment, 44 (12), 2396–2412.

[27] Palyvos J.A. 2008. A survey of wind convection coefficient correlations for building envelope energy system's modelling. Applied Thermal Engineering, 28, 801–808.

[28] Meir IA. et al. 2004. The vernacular and the environment towards a comprehensive research methodology, The 21th Conference on Passive and Low Energy Architecture. Eindhoven, the Netherlands, 19–22 September 2004.

[29] Ito N., Kimura K., Oka, J. 1972. IIA field experiment study on the convective heat transfer coefficient on exterior surfaces of a building. ASHRAE Transactions, 68: 184.

[30] Mustafa AF., Costa F.J. 1983. Al Jarudiya: A model for low rise/high density developments in the Eastern provinces of Saudi Arabia, in Islamic Architecture and Urbanism, ed. A. Germen, University of Dammam, Saudi Arabia, pp. 239–256.

[31] Brarozzi GS., Imbabi MSE, Nobile E., Sousa ACM. 1999. Physical and numerical modelling of a solar Chimney-based ventilation system for buildings. Building and Environment, 27(4), 433–445.

[32] Qingyan, Chen, Leon, R., Glicksman. 2001. Simplified methodology to factor room air movement and the impact on thermal comfort into design of radiative, convective and hybrid heating and cooling systems. ASHRAE RP-927, ASHRAE.

[33] Taleghani M., Tenpierik M., van den Dobbelsteen A., de Dear. R. 2013. Energy use impact of and thermal comfort in different urban block types in the Netherlands. Energy and Buildings, 67 (0), 166–175.

[34] Taleghani M., Tenpierik M. and Dobbelsteen A. 2013. The effect of different transitional spaces on thermal comfort and energy consumption of residential buildings. in 7th Windsor Conference: The changing context of comfort in an unpredictable world Cumberland Lodge. 2012, Network for Comfort and Energy Use in Buildings, Windsor, UK.

[35] Yasa E., Fidan.G, Tosun M., 2014. Analysis of historic buildings in terms of their microclimatic and thermal comfort performances "Example of Konya Slender Minaret Madrasah". Journal of Architectural Engineering Technology, 3 (3), 2168–9717. doi:10.4172/2168-9717.1000126.

[36] Yasa, E. 2010. A method developed in the optimization of courtyard building shape according to climatic performance in different climate regions. Ph.D. thesis. Institute of Science and Technology, Istanbul Technical University, February 2010.